Comparative study of two mid-littoral rockpool ecosystems in relation to marine pollution

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COMPARATIVE STUDY OF TWO MID-LITTORAL ROCKPOOL ECOSYSTEMS IN RELATION TO MARINE POLLUTION

by

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1. INTRODUCTION

Community structure has been defined as the complex of individuals belonging to different species in a biotic community (Odum, 1962). An unfavourable factor such as pollution can result in detectable changes in this structure by altering community parameters. One such parameter, species diversity, has been used quite extensively to evaluate pollution because it gives a quantitative aspect of community structure with the use of mathematical expressions (Wilhm and Dorris, 1968).

Coastal marine waters are in certain areas under the continuous influence of pollutants entering their ecosystems through industrial effluents and sewage discharges. Heavy metals are considered a principal source of contamination, since they can alter the water quality and have deleterious effects on aquatic organisms (Goldman, 1965).

The north-east coast of England provides an interesting example of the affect of pollution on marine waters. It shows a remarkable pollution gradient going from the unpolluted coasts of Northumberland to the heavily polluted waters of County Durham (Bellany et al., 1967). Work, on this coast, has been carried out by Jones (1971), Burrows and Pybus (1971), Edwards (1972), which relate to the fact that the coast of Durham has been subject to long term "chronic" pollution by both domestic and industrial dischargees. The work has been mainly carried out on sub-littoral ecosystems and has indicated that the main effect is a reduction in the extent of productivity of the kelp forest ecosystem brought about by reduction in light intensity, due to

suspended matter (Bellamy et al., 1968).

Jones (1971) continued the work studying the infauna of the kelp holdfast and invoked with sewage and toxicoids to explain the difference in fauna between polluted Durham and unpolluted Northumberland systems.

It was decided to make a similar comparison using the total ecosystem of mid-littoral rockpools to gain comparative material with special reference to species diversity, as an important community parameter and the effects of toxic heavy metals on marine communities.

By way of introduction it would be useful to look briefly at the use of diversity indices and the factors influencing the bioaccumulation of heavy metals by the flora and fauna of the aquatic systems.

1.1 Diversity indices

Diversity indices are ratios between the number of species and "importance" values (numbers, biomass, productivity of individuals) (Odum, 1971). They describe community structure and summarize large amounts of information (Wilhm and Dorris, 1968).

Early workers simply used the number of species per sample or per litre as an index of diversity. Such a method failed to distinguish between samples in which the relative abundance was different. Later, different hypotheses were developed on the distribution of individuals among the species. The main ones chronologically are:

(1) the 'geometric (Motomura, 1932),

(2) the 'logarithmic' (Fischer, Corbet and Williams, (1943),

(3) the 'lognormal' (Preston, 1948).

(4) Simpson's (1949) based on the probability theory, and

(5) the random niche controlled (McArthur, 1957).

"Which one is 'best' depends upon which one proves in practice to give the most reliable, surprising ecological predictions and the greatest insight" (Lloyd et al., 1968). However, as pointed out by Wilhm and Dorris (1968), there are several criteria which make a diversity index preferable to another.

(1) A diversity index should be independent of sample size

(2) It should reflect not only the distribution of species but should include the relative importance of each species in the community and

(3) When biomass units are used the index should be dimensionless, otherwise the values generated, will depend upon the chosen weight units.

One such index which satisfies these requirements is Shannon-Wiener formula.

1.2 Shannon - Wiener formula

Margalef (1956) proposed analysis of mixed-species populations by methods deriving from information theory. Pielou (1966) stated that "Diversity is thus equated with the amount of uncertainty which exists regarding the species of an individual selected at random from a population. The more species there are and the more even their representation, the greater the uncertainty and hence the greater the diversity". Information content is a measure of uncertainty and thus a reasonable measure of diversity.

Margalef's currently widely accepted diversity index is

a modification of the Shannon - Wiener formula.

$$H = -\sum_{i=1}^{s} p_i \log_2 p_i$$

The proportions p_i are intended to be the true proportions from the population being sampled. In practice the index is computed according to the formula

$$H = -\sum_{i=1}^{s} \frac{Ni}{N} \log_2 \frac{Ni}{N}$$

where H = information content of sample (bits/ind) =
= index of species diversity
s = number of species
Ni = number of individuals of i^{th} species in a sample and
N = total number of individuals belonging to all species in a sample.

One of the main components of Shannon - Wiener function is "equatability" or "evenness" of individuals among species (Lloyd and Geraldi, 1964). A greater number of species and a more even distribution among species would increase species diversity.

However, the use of numbers in communities of individuals considerably differing in size and weight, includes certain disadvantages. Ghilarov (1972) suggested the study of energetic diversity since all the components of an ecosystem are supported by energy flowing through the system. Similarly, Dickmann (1966) working on plankton community found that only the use of relative productivity of the various species appeared to be more sensetive to changes in community structure. Unfortunately, energetic characteristics of many species are not available, neither are the turnover rates to calculate productivity, so we have to compromise with the use of

biomass of populations that form a community "bearing in mind that energy requirements of individuals are more or less proportional to their biomass" (Ghilarov, 1972).

The final formula used in this study is

$$H_b = - \sum_{i=1}^{s} \frac{Bi}{B} \log_2 \frac{Bi}{B}$$

where H_b = diversity (bits per weight units)

Bi = biomass of all individuals of i^{th} species in a sample and

B = biomass of all individuals belonging to all species in a sample, i.e. $B = \sum_{i=1}^{s} Bi$

1.3 Heavy metals

Research concerning the effects of heavy metals as marine pollutants has been carried out by a number of workers; however, far too little is known about their ecological effects because their behaviour varies in different environments and in different organisms.

a. Distribution of heavy metals in the coastal environment

Trace elements are distributed among all phases of a marine environment i.e. sediment, water and biota. The distribution of heavy metals in each of these components is controlled by the chemical and physical state of these elements as they are introduced into the sea, the chemical and physical conditions of the coastal area such as pH, Eh, temperature, salinity, geomorphology etc., and also the affinity of these elements either for accumulation by biota or for adsorption on particular matter (Gross et al., 1970).

Heavy metals are removed by marine organisms by absorption and adsorption and in several cases accumulate in their body.

During the process of uptake ions enter the organism either actively or passively. This process is influenced by environmental variables. Gutneckht (1963) studied the uptake of Zn^{65} by benthic marine algae and noticed that increase in pH promoted the uptake and retarded the loss of Zn^{65}, whereas exposure to light stimulated both processes. Changes in temperature had only a slight effect. The uptake of zinc depends also on the concentration of the metal in solution as well as the concentration of the other cations (Bachmann, 1963). Mandelli (1969) found a positive correlation between the log copper uptake - algal biomass and the temperature and a negative correlation for the same ratio regarding the salinity parameter.

Accumulation process is uptake against a concentration gradient, that is the internal concentration is greater than theconcentration in the external environment. Concentration factors for different metals vary considerably from species to species. Molluscs, for example, are able to concentrate trace metals up to many hundreds of times that level found in their environment (Pringle et al., 1968). Certain algal species accumulate zinc and cobalt so effectively that they could be used as biological filters in polluted waters (Coleman et al., 1971).

There are certain factors determining the concentration of metals in an organism. Bryan (1971) found that in the brown seaweed Fucus vesiculosus concentration of metal increases considerably with the distance of the tissue from the growing point; so time or age can be an important factor. The affinity of the metals is also important. The order of affinity for brown algae is generally: Pb > Mn > Zn > Cu > Cd > Co > Ni

(Pringle et al., 1968). The same authors concluded that the accumulation rates are dependent upon the environmental metal concentration, the temperature, the time of exposure and the species used.

(b) Toxic effects of heavy metals

The relative toxicity of a certain element varies from species to species for any given concentration, all other factors remaining constant (Pringle et al., 1968). It may also vary with life history and prior exposure to the metal or to other environmental factors.

Skidmore (1964) found that toxicity of zinc compounds to aquatic animals is modified by the hardness of the dilution of water and the concentration of dissolved oxygen and temperature. The resistance of the animal depends upon acclimatisation of the organism to the element and possibly its age.

Eisler (1971) studied toxic effects of cadmium on mummichops and found that the susceptibility of the animals increased at high temperature and low salinity.

Maloney and Palmer (1956) reported a selective toxicity of copper to thirty fresh water algal cultures, rather than a general effect, at concentrations between 0.05 and 0.5 mg Cu/ml.

2. MATERIALS AND METHODS

2.1 Area and ecosystems selected for study

The investigation was carried out on mid-littoral rockpool systems at two different areas along the north-east coast of England. The two sites selected were the limestone platform north of Bamburgh and the magnesium limestone coast near Marsden rock, southern the Tyne estuary (Fig. 1).

Coastal waters near Bamburgh are relatively unpolluted due to a lack of industries, mining and highly populated areas. On the contrary, Tyne estuary receives everyday the discharges of a large industrial connurbation plus a variety of mixed industrial wastes. Faecal bacterial counts frequently reach 100.000 organisms per litre (Jones, 1970). The site was chosen southern the estuary because the tidal wave of the coast and its residual current are both moving southwards (Starkie, 1970).

In an attempt to receive some uniformity, the location of the rockpools on the coast, the surface to volume ratio and the characteristic flora and fauna were taken into consideration. The distinct zonation at Bamburgh (Fig. 2) enabled the selection of the rockpools, whereas a lack of zonation at South Shields (Fig. 3) made necessary the use of other parameters, such as characteristic flora and fauna, tidal level etc. Figure two shows the distinction between the zone of Pelvetia canaliculata, the barnacles zone and the zone of Mytilus edulis. Above Pelvetia canaliculata the rocky surface was covered with dark yellow lichens, possibly species of the

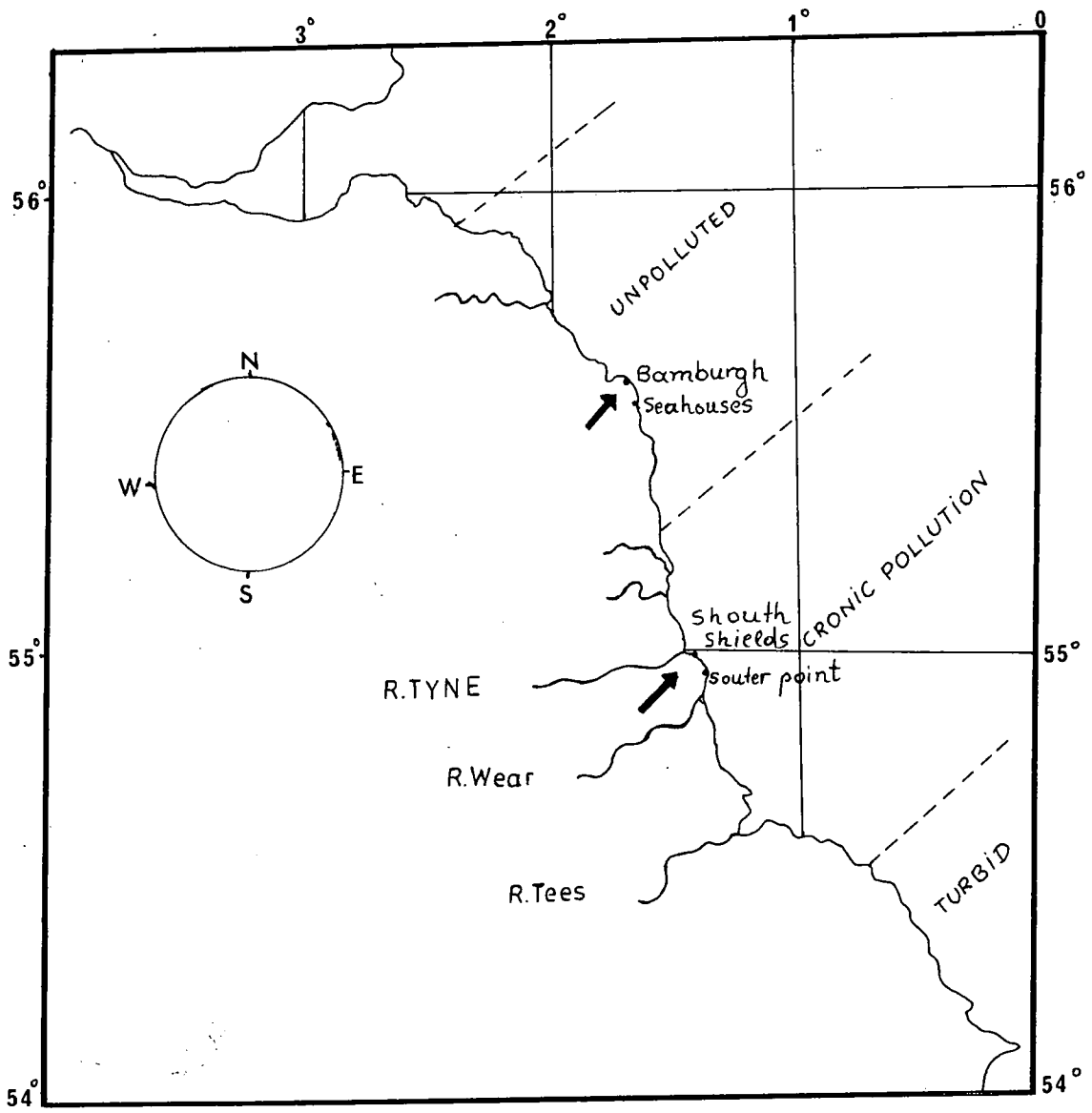


Fig. 1: Location of the sampling stations in the study area.

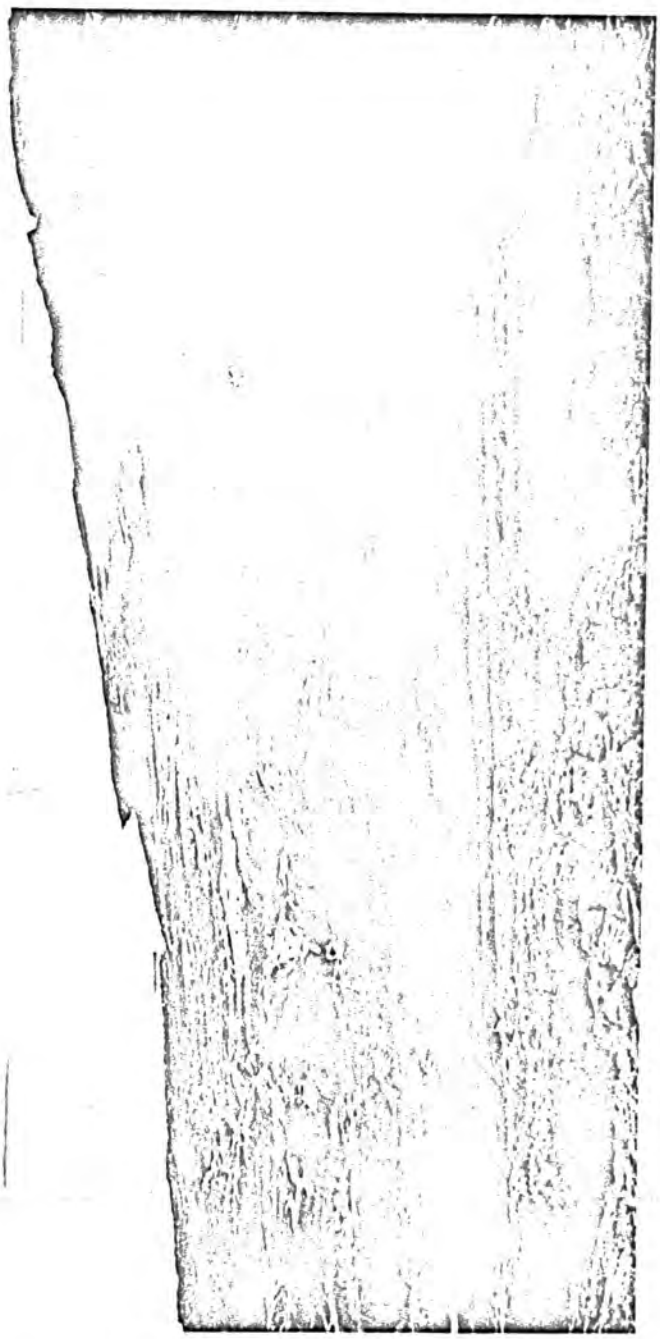


Fig. 2: Sampling site at Bamburgh

Fig. 3: Sampling site at South Shields

genus Xanthonia. The seven selected rockpools were located at the intertidal barnacle zone otherwise called eulittoral zone (Lewis, 1964).

The investigation was carried out on rockpools. Rockpools are very useful for ecological studies; they are well-defined ecosystems containing small volumes of water and having few but characteristic species. One of their main characteristics is a strong competition between sessile animals and plants for attachment areas, because the number of niches available is limited (North, 1964). They are also vulnerable to changes and since they are under continuous stress, an unfavourable factor such as pollution can result in obvious and detectable effects on the structure of their communities. Studies on their benthos are also very effective since "attached algae, because of their sedentary nature tend to integrate the effects of long-term exposure to adverse conditions" (Borowitzka, 1972). As pointed out by the same author, benthic algae are also part of the lowest trophic level and anything that influences them can also have an effect on the higher trophic levels.

2.2 Measurement of species diversity

A brief survey of the flora was carried out in order to detect any distinct differences between the species of the two sites (Table I). Seven rockpools at both areas were selected.

Species diversity was measured by placing a 50 by 50cm square grid and removing all plants found in the quadrant. Fifteen samples were taken from each site. Plants were removed from the pools by the use of a knife and error was minimized by collecting the microscopic flora of the pools

Table I

A LIST OF THE MAIN SPECIES FOUND AT EACH OF THE SITES

Species	Bamburgh	South Shields
	Chlorophyta	
Ulva lactuca	x	x
Enteromorpha spp.	x	x
E. Compressa		x
Cladophora rupestris	x	x
C. [glaucescens]	x	
	Phaeophyta	
Laminaria digitata	x	x
L. saccharina		x
Fucus vesiculosus	x	x
F. serratus		x
Ascophyllum nodosum		x
Halidrys siliquosa	x	
Asperococcus bullosus	x	x
	Rhodophyta	
Rhodymenia palmata	x	x
Ptilota plumosa		x
Plumaria elegans		x
Corralina officinalis	x	x
Ceramium rubrum		x
Chondrus crispus	x	x
Polysiphonia lanosa	x	
Lithothamnion spp.	x	

x; species occuring at the site

as completely as possible. Specimens were taken in plastic bags to the laboratory, where they were sorted by species and left in the oven for 24 hours at 103°C. Species were only recognized and not identified by their name. Odum (1971) points out that errors due to failure in distinction between similar species are not usually found in the same sample and different life stages are already part of diversity. Seasonal variation is also considered as source of error. However, during the course of this study a simultaneous sampling of the two areas was practically impossible.

2.3 Heavy metal analysis

a. Water analysis

The average concentration of heavy metals in sea waters usually falls below the detection limits of commonly used equipment and preconcentration is normally necessary (Soman et al., 1969). Chelatin resins are usually used to concentrate the trace elements and seperate them from major components. During the course of this study the use of such a technique was practically impossible. Therefore, water samples were only treated with concentrated nitric acid and perchloric acid to make all trace metals associated with dissolved and particulate organic matter available in solution.

Water samples were collected from both sites. Sea water was passed through a Sinta funnel (Glass Grade 2) into a 100 ml polythylene bottle previously cleaned with hydrochloric acid and rinsed with distilled water. The samples were taken directly to the laboratory and immediately prepared for analysis in order to avoid the adsorption of metal ions by the container walls and the growth of microorganisms. 10 ml of

nitric acid plus 5 ml of perchloric acid were added to 100 ml of the sampled water. Samples were placed on a sand bath and evaporated till 1 - 2 ml were left in the flask. The residue was made up to 100 ml with distilled water and taken to the atomic absorption spectrophotometer (Perkin Elmer 403). Triplicates for each sample and suitable blank corrections were also made.

b. Suspended matter analysis

The procedure followed was described by Preston et al., (1972). Five litres of sea water were passed through Millipore filter papers. The filter papers were then placed in a wide beaker where 100 ml of 0.1 N hydrochloric acid and 1 ml hydrogen peroxide were also added. The filters were leached by boiling while a clock-glass prevented foreign matter from entering the beaker. When the liquid had evaporated to about 20 ml it was transferred with the help of demineralized water, to a 50 ml flask and made up to 30 ml. Both beakers and flasks had been acid washed before use. Triplicates from each sample were prepared. To avoid errors resulting from reagent contamination, blanks with reagents only were used. The samples were analyzed by the atomic absorption spectrophotometry.

c. Sediment analysis

Samples from rockpools from both areas were taken and analyzed according to the technique described by Cross et al., (1970). The samples were carried back to the laboratory in pre acid-washed glass containers and left immediately in a drying oven at 103^{0}C for 24 hours. To obtain an approximately uniform particle size the samples were sifted and then triplicates of 2 gm were made for each site. The samples were

left standing in 50 ml of 0.1 N HCl for 24 hours and then were ground with a pestle and diluted to 100 ml with 0.1 N HCl. Two hours later they were filtered through Whatman 42 filter paper that had been rinsed with 0.1 N HCl. 50 ml of 0.1 N HCl were added to each sample and the concentration of heavy metals was determined by atomic absorption spectrophotometry. Since reagent contamination for heavy metals may be significant, suitable blank corrections were also made.

d. Analysis of biological material

i) Collection of plant and animal material

The species selected for plant analysis were: Ulva lactuca, Laminaria digitata, L. saccharina, Fucus serratus, F. vesiculosus and Rhodymenia palmata. All specimens were taken from the rockpools under study. Bryan (1971) showed that the concentration of zinc varies in different parts of certain algal species. An attempt was made to find out whether other heavy metals behave similarly in order to avoid errors resulting from comparison between different parts of the same species. Two species of Fucus and Laminaria were used as test organisms.

For animal analysis three species were chosen: Patella vulgata, Littorina littorea and Carcinus maenas. Patella and Littorina were seperated from their shells and the concentration of heavy metals in the flesh was examined seperately. Nicklese et al., (1972) found that the concentration of cadmium in Patella is related to the size of the animal and its position on the shore. Therefore, all specimen were taken from the rockpools of the same level, at each site and young and adult stages were seperately analyzed.

ii) Plant analysis

The procedure followed is a modification of the dry ashing technique, described by Johnson and Ulrich (1959).

The algae were taken back to the laboratory in polyethylene bags where they were washed thoroughly with distilled water and dried at 103°C for 24 hours. The dried material was ground with mortar and pestle and triplicates of about 0.6 gm of each species at each site were weighed into acid washed, dust free, silica crucibles. The crucibles were then placed in a lead-lined muffle furnace at 490°C for 24 hours. In order to obtain an inorganic ash weight the samples were weighed organic. The ash was then dissolved in 4 ml of 2 N hydrochloric acid. The solutions were filtered through Whatman 1 filter paper that had been rinsed with 2 N HCl and made up to 25 ml. The analysis was then carried out on a Perkin-Elmer 403 Atomic Absorption spectophotometer. Blanks were also prepared with reagents only.

iii) Animal analysis

The analysis of Patella vulgata and Littorina littorea was carried out by following the dry ashing procedure whereas a modification of wet ashing technique was used for the analysis of Carcinus maenas (Johnson and Ulrich, 1959). The samples were dried in the oven at 103°C for 24 hours. The dried material was then ground, dissolved in 20 ml of nitric acid and left overnight. 5ml of hydrochloric acid and perchloric acid were then added and the solution was evaporated on a warm sand bath till ignition. The residue was diluted with 20 ml of demineralized water, filtered through Whatman 42 filter paper and made up to 100 ml dilution with the use of demineralized water. Blanks were also

prepared with reagents only. Samples and blanks were analyzed by the atomic absorption spectrophotometry.

3. RESULTS

3.1 Species diversity and other indices

To calculate species diversity fifteen samples from rockpools of each site were taken. Results for the indices of evenness and dominance as well as for the index of species diversity per sample, are reported in tables II and III. In the same tables, the number of species and biomass per sample are given. The number of species in the rockpools of Bamburgh ranged between seven and twelve, whereas the samples form South Shields contained five to thirteen species. At South Shields, there were also recorded wider fluctuations in biomass, the values ranging between 37 to 390 gms dry weight per sample, whereas the corresponding values at Bamburgh varied from 52 to 266 gms dry weight.

Mean values for all measured components are given in table IV. It is worth pointing out the decrease in species diversity at South Shields. Similarly, the indices of evenness and dominance showed lower values at South Shields whereas the total number of species present and the total biomass showed an increase.

3.2 Heavy metal analysis

a) Analyses of water, suspended matter and sediment

Concentrations of zinc, copper, lead, cobalt and cadmium in water at both sites are listed in table V. Although there is a wide range of variation in the levels of most trace elements in sea waters, the values obtained

are too high compared to those available from the literature e.g. Preston (1973). Higher values are either due to the use of a crude technique or to contamination deriving from reagents or containers used.

Concentrations of heavy metals in sediment and suspended matter are also reported in table V. South Shields exhibits the highest mean concentrations. Lead follows zinc for both analyses whereas cadmium shows the lowest values. Statistical analysis of the values showed no significant difference between the concentrations in the suspended matter. However, average concentrations of lead and zinc in the sediment are significantly higher than those at Bamburgh (table X).

b) Plant analysis

The concentration of heavy metals per dry weight of plant material are listed in the tables VI and VIII. Tables VII and IX record the corresponding values on an ash weight basis. Zinc shows the highest concentrations followed by either copper or lead, depending on the species or part of the specimen used. Cadmium shows the lowest values at both sites. Brown algae exhibit higher concentrations of heavy metals than the green algae Ulva lactuca and the red Rhodymenia palmata. The highest concentrations of zinc were observed in Fucus serratus.

By a statistical analysis only zinc, copper and lead in the two species of Fucus and copper in Ulva lactuca showed a significant defference between the sites (table XI). No significant difference was observed in the three different parts of tissue of the selected plants at Bamburgh. At South Shields zinc was the only heavy metal which varied

significantly in the three different parts of Laminaria digitata and Fucus vesiculosus. The three parts of lamina analysed were: a) from the starting point of lamina to 200 mm, b) from 200 to 500 mm and c) from 500 mm to the end of the plant. Figures 4 and 5 show certain of these results in histogram form. Figure 4 presents the concentration of all five metals in Laminaria saccharina and L. digitata at South Shields. Although fluctuations in the concentrations are observed, no consistent pattern is followed. Figure 5 shows the corresponding concentrations in Fucus vesiculosus at Bamburgh and F. serratus at South Shields. The only significant difference is found in zinc in the three parts of Fucus serratus at South Shields.

c) Animal analysis

In tables VIa and VIIIa the high concentrations of zinc in the flesh of Patella is the outstanding feature. The other trace elements examined showed no consistent pattern of variation. The shell of Patella examined seperately showed low concentrations of zinc and high concentrations of lead, cobalt and cadmium. High concentrations of all metals were detected in the body of Carcinus maenas.*

The major points arising from statistical analysis of the results are the significantly higher concentrations of zinc and lead (table XIa) in the flesh of Patella at South Shields and the similarly high levels of lead in the soft parts of Littorina and the body of Carcinus maenas. Cobalt was significantly higher in the flesh of young limpets, whereas cadmium showed a significant difference in the body of the crab. Comparison of the concentrations of trace elements

* Tables VIIa and IXa record the above values on an ash weight basis.

in the soft parts of Patella between young and old stages showed no significant difference.

Table II

Bamburgh: Diversity and other indices

No. of samples	No. of species	Biomass gm. dry wt.	Species diversity $H = -\sum \frac{Bi}{B} \log \frac{Bi}{B}$	Evenness $e = \frac{H}{\log S}$	Dominance $c = (\frac{Bi}{B})^2$
1.	12	105.81	1.17	1.08	0.47
2.	12	266.23	2.54	2.35	0.89
3.	11	145.17	2.34	2.25	0.25
4.	8	200.63	0.81	0.90	0.76
5.	9	117.05	3.01	3.15	0.53
6.	10	88.27	2.70	2.70	0.38
7.	8	140.70	3.05	3.38	0.61
8.	7	60.44	2.20	2.60	0.34
9.	9	251.55	2.54	2.66	0.24
10.	11	150.63	2.26	2.17	0.65
11.	12	180.25	2.37	2.20	0.42
12.	8	140.58	1.85	2.50	0.49
13.	10	80.93	2.60	2.60	0.53
14.	8	73.40	2.10	2.33	0.26
15.	9	140.58	2.34	2.45	0.65

Table III

South Shields: Diversity and other indices

No. of Sample	No. of species	Biomass	Species diversity $H=\sum \frac{Bi}{B} \log \frac{Bi}{B}$	Evenness $e=\frac{H}{\log S}$	Dominance $c=(\frac{Bi}{B})^2$
1.	7	70.56	1.58	1.88	0.47
2.	8	230.70	0.78	0.86	0.75
3.	7	36.88	1.53	1.81	0.51
4.	8	70.07	2.35	2.60	0.22
5.	11	200.79	0.88	0.84	0.74
6.	12	389.73	0.89	0.82	0.65
7.	9	148.08	1.93	2.02	0.35
8.	5	69.37	2.07	2.96	0.26
9.	13	82.31	2.34	2.10	0.31
10.	11	66.02	2.46	2.36	0.23
11.	14	50.47	2.99	2.87	0.45
12.	8	116.23	1.58	1.75	0.16
13.	12	80.75	2.67	2.47	0.23
14.	10	83.99	1.70	1.70	0.48
15.	11	138.23	1.58	1.52	0.21

Table IV

Mean values of diversity and other indices, at both sites

Site	Total no. of species present	Total biomass	Species diversity	Evenness Index	Index of dominance
Bamburgh	13	1.912.11	2.26±0.28	2.32±0.23	0.50±0.12
South Shields	16	1.835.18	1.82±0.21	1.90±0.23	0.40±0.12

Table V

Concentration of heavy metals (ppm) in sea water, suspended matter and sediment

BAMBURGH	Zn	Cu	Pb	Co	Cd
Seawater	0.045	0.072	0.39	0.35	0.134
suspended matter	1.09±0.32	0.37±0.08	0.82±0.12	0.45±0.04	0.09±0.03
sediment	3.16±0.98	9.50±0.62	0.88±0.10	5.06±0.32	1.56±0.19

SOUTH SHIELDS	Zn	Cu	Pb	Co	Cd
seawater	0.077	0.084	0.43	0.39	0.15
suspended matter	2.26±0.86	0.75±0.18	1.58±0.35	0.92±0.08	0.16±0.03
sediment	29.25±4.24	17.00±1.93	22.12±3.73	7.80±0.93	3.39±0.62

Table VI

Bamburgh: Bioaccumulation of heavy metals (ppm dry wt) by the flora and fauna

FLORA	Zn	Cu	Pb	Co	Cd
Ulva lactuca	16.04±2.90	3.89±0.28	3.64±0.32	1.11±0.11	0.71±0.10
Laminaria digitata (0-200mm)	36.98±4.18	8.58±1.32	6.22±0.93	3.82±0.65	2.81±0.18
L. digitata (200-500mm)	40.46±6.53	7.16±0.06	6.50±1.37	5.52±0.93	2.02±0.22
L. digitata (500mm)	48.64±5.84	6.13±0.75	6.83±1.70	3.42±0.60	1.92±0.38
Fucus vesiculosus (0-200mm)	29.13±3.44	4.15±0.28	4.45±0.65	3.51±0.48	1.37±0.32
F. vesiculosus (200-500mm)	48.54±5.75	9.42±1.73	5.90±0.61	4.45±0.40	2.64±0.64
F. vesiculosus (500mm) *	-	-	-	-	-
Rhodymenia palmata	19.96±1.64	4.75±0.66	2.92±1.20	1.28±0.14	0.79±0.08

* material for analysis not available

Table VIa

FAUNA	Zn	Cu	Pb	Co	Cd
Littorina littorea	53.95±5.64	29.94±2.96	7.34±0.42	4.33±0.65	2.60±0.20
Patella vulgata (A) (soft parts)	58.06±2.66	14.36±1.30	7.03±0.93	1.05±0.10	5.10±0.38
P. vulgata (Y) (soft parts)	72.26±6.35	-**	6.44±0.75	0.78±0.23	2.98±0.12
P. vulgata (shell)	3.56±0.92	3.01±0.80	36.40±3.12	33.68±2.14	6.62±0.08
Carcinus maenas	53.04	14.60	10.76	26.92	7.42

** Data not available
Y. Young
A. Adult

Table VII

Bamburgh: Bioaccumulation of heavy metals (ppm ash wt) by the flora and fauna

FLORA	Zn	Cu	Pb	Co	Cd
Ulva lactuca	102.00	24.81	23.10	7.07	4.00
Laminaria digitata (0-200mm)	140.09	29.33	26.09	23.20	10.36
L. digitata (200-500mm)	212.92	36.73	34.25	29.04	9.38
L. digitata (500mm)	279.04	31.82	38.75	20.09	11.22
Fucus vesiculosus (0-200mm)	192.58	23.36	25.18	19.70	9.73
F. vesiculosus (200-500mm)	173.16	35.62	20.13	15.90	8.15
F. vesiculosus* (500mm)	-	-	-	-	-
Rhodymenia palmata	129.60	32.32	18.29	8.49	5.35

* material for analysis not available

Table VIIa

FAUNA	Zn	Cu	Pb	Co	Cd
Littorina littorea	273.94	152.04	36.03	36.03	12.74
Patella vulgata (A) (soft parts)	455.56	112.73	55.20	8.34	40.52
P. vulgata (Y) (soft parts)	662.44	- **	54.12	10.61	54.12
P. vulgata (shell)	3.64	3.03	37.32	34.49	6.79

** Data not available
Y. Young
A. Adult

Table VIII

South Shields: Bioaccumulation of heavy metals (ppm dry wt) by the flora and fauna

FLORA	Zn	Cu	Pb	Co	Cd
Ulva lactuca	25.45±3.70	18.64±1.30	4.99±0.51	1.96±0.37	5.07±0.70
Laminaria digitata (0-200mm)	27.55±2.10	13.73±4.12	6.86±0.19	3.37±0.85	2.69±0.80
L. digitata (200-500mm)	43.70±0.98	9.09±0.30	15.07±0.82	3.58±0.12	3.70±0.22
L. digitata (500mm)	59.26±4.37	10.00±0.61	10.37±0.35	4.64±0.23	1.74±0.37
Laminaria saccharina (0-200mm)	29.13	13.24	8.84	6.20	2.10
L. saccharina (200-500mm)	44.87	25.22	12.61	6.72	3.06
L. saccharina (500mm)	42.78	9.65	9.64	6.38	0.92
Fucus serratus (0-200mm)	171.34±6.80	12.70±1.76	13.30±0.68	7.43±0.87	2.17±0.54
F. serratus (200-500mm)	108.36±5.16	8.09±2.10	7.71±1.15	5.39±0.98	2.13±0.33
F. serratus (500mm)	75.00±2.10	5.87±0.85	6.61±0.90	4.73±0.60	2.49±0.68
Rhodymenia palmata	21.20±3.12	9.37±1.08	6.21±1.15	1.04±0.30	1.04±0.50

Table VIIIa

FAUNA	Zn	Cu	Pb	Co	Cd
Littorina littorea	73.64±4.60	29.70±0.30	18.87±1.30	5.86±0.72	2.82±0.12
Patella vulgata (A) (soft parts)	112.58±10.25	21.02±0.28	17.82±1.18	5.18±0.68	6.19±0.30
P. vulgata (Y) (soft parts)	118.24±11.20	20.25±0.46	23.79±1.38	5.87±0.56	1.98±0.08
P. vulgata (A) (shell)	3.43±0.72	3.54±0.04	42.82±0.98	39.03±2.69	7.62±0.60
P. vulgata (Y) (shell)	7.47±1.38	3.89±0.02	45.49±1.12	31.33±2.70	*
Carcinus maenas	69.30	37.94	30.67	33.46	9.40

Y. Young
A. Adult
* data not available

Table IX

South Shields: Bioaccumulation of heavy metals (ppm ash wt) by the flora and fauna

FLORA	Zn	Cu	Pb	Co	Cd
Ulva lactuca	171.29	120.50	32.49	12.65	11.13
Laminaria digitata (0-200mm)	92.33	49.08	23.91	11.12	12.54
L. digitata (200-500mm)	189.93	41.45	70.78	17.89	18.42
L. digitata (500mm)	236.75	35.87	41.35	37.39	7.79
Laminaria saccharina (0-200mm)	121.50	52.63	36.90	25.88	8.78
L. saccharina (200-500mm)	159.80	83.45	48.33	27.93	10.25
L. saccharina (500mm)	152.33	34.35	34.34	22.60	3.25
Fucus serratus (0-200mm)	770.40	56.66	58.37	32.12	13.60
F. serratus (200-500mm)	555.25	41.40	74.03	33.77	10.69
F. serratus (500mm)	357.40	27.98	42.13	22.56	11.80
Rhodymenia palmata	153.25	67.61	40.32	7.51	7.54

Table IXa

FAUNA	Zn	Cu	Pb	Co	Cd
Littorina littorea	403.12	135.21	103.77	35.75	15.44
Patella vulgata (A) (soft parts)	509.31	117.66	96.45	29.38	36.36
P. vulgata (Y) (soft parts)	632.55	102.11	141.96	29.88	10.16
P. vulgata (A) (shell)	3.52	3.64	43.98	36.78	7.85
P. vulgata (Y) (shell)	7.90	4.03	46.38	32.40	- *
Carcinus maenas *	-	-	-	-	-

Y. Young
A. Adult
* data not available

Table X

Bamburgh
South Shields : Statistical analysis of suspended matter and sediment

	Zn		Cu		Pb		Co		Cd	
	x^2	P	x^2	P	x^2	P	x^2	P	x^2	P
suspended matter	0.40	n.s	0.12	n.s.	0.24	n.s.	0.16	n.s.	0.01	n.s.
sediment	20.98	$P<0.001$	2.12	n.s.	5.64	$p<0.01$	0.58	n.s.	0.68	n.s.

P, level of significance
n.s. not significant

Table XI

Bamburgh:
Statistical analysis of the flora and fauna
South Shields:

FLORA	Zn		Cu		Pb		Co		Cd	
	x^2	P	x^2	P	x^2	P	x^2	P	x^2	P
Ulva lactuca	1.16	n.s.	9.66	$p<0.01$	0.21	n.s.	0.22	n.s.	3.28	n.s.
Laminaria digitata (0-200mm)	1.38	n.s.	1.18	n.s.	0.03	n.s.	0.03	n.s.	0.00	n.s.
L. digitata (200-500mm)	0.13	n.s.	1.98	n.s.	3.38	n.s.	0.41	n.s.	0.22	n.s.
L. digitata (500mm)	1.04	n.s.	0.93	n.s.	0.73	n.s.	0.18	n.s.	0.00	n.s.
Fucus serratus F. vesiculosus (0-200mm)	101.00	$p<0.001$	4.34	$p<0.05$	4.42	$p<0.05$	1.44	n.s.	0.18	n.s.
F. serratus F. vesiculosus (200-500mm)	22.94	$p<0.001$	0.10	n.s.	0.24	n.s.	0.10	n.s.	0.00	n.s.
Rhodymenia palmata	0.04	n.s.	1.51	n.s.	1.18	n.s.	0.03	n.s.	0.04	n.s.

n.s. not significant
P. level of significance

Table XIa

FAUNA	Zn	P	Cu	P	Pb	P	Co	P	Cd	P
Littoria littorea (soft part)	3.03	n.s.	0.00	n.s.	5.07	$p<0.05$	0.22	n.s.	0.00	n.s.
Patella vulgata (A) (soft parts)	16.14	$p<0.001$	1.25	n.s.	4.64	$p<0.05$	2.73	n.s.	0.10	n.s.
P. vulgata (Y) (soft parts)	11.08	$p<0.001$	-	n.s.	9.95	$p<0.01$	3.88	p 0.05	0.20	n.s.
P. vulgata (shell)	0.00	n.s.	0.04	n.s.	0.52	n.s.	0.32	n.s.	0.07	n.s.
Carcinus maenas	2.16	n.s.	0.23	n.s.	9.56	$p<0.01$	0.70	n.s.	9.56	p 0.01

n.s., not significant
P, level of significance

Table XII

Bamburgh: Statistical analysis of parts and life stages of selected species

	Zn		Cu		Pb		Co		Cd	
SPECIES	x^2	P	x^2	P	x^2	P	X^2	P	x^2	p
Laminaria digitata (0-180mm) (180-520mm) (520mm)	1.69	n.s.	0.40	n.s.	0.03	n.s.	0.57	n.s.	0.20	n.s.
Fucus vesiculosus (0-180mm) (180-520mm) (520mm)	4.84	n.s.	2.04	n.s.	0.20	n.s.	0.10	n.s.	0.16	n.s.
Patella vulgata (adult) (soft parts) (young)	1.54	n.s.	* -	n.s.	0.02	n.s.	0.02	n.s.	0.54	n.s.

n.s.. not significant
* no data availeble

For 180mm read 200 mm
For 520mm read 500 mm

Table XIII

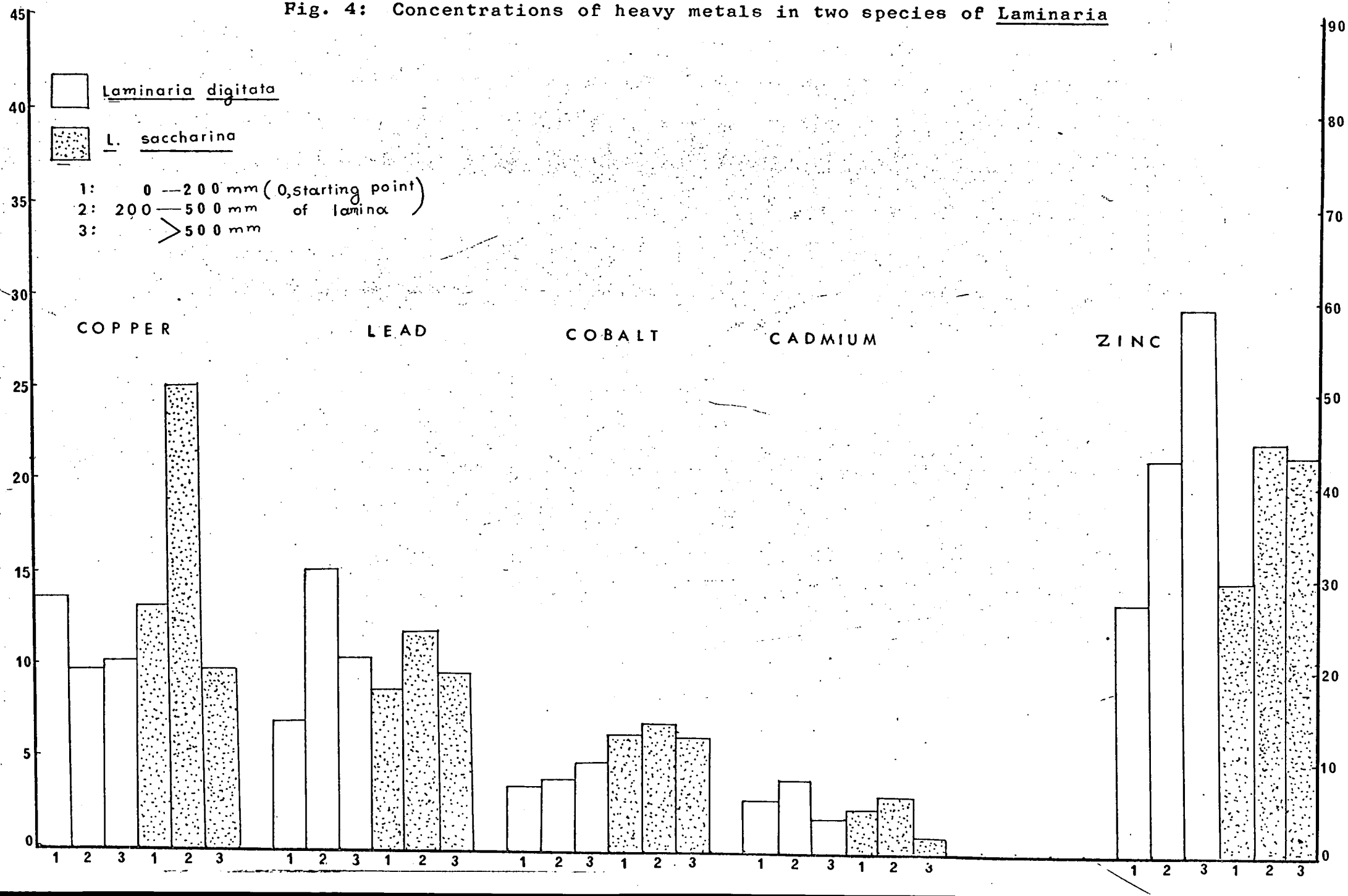
South Shields: Statistical analysis of parts and life stages of selected species

	Zn		Cu		Pb		Co		Cd	
SPECIES	x^2	P	x^2	P	x^2	P	x^2	P	x^2	P
Laminaria digitata (0-180mm) (180-520mm) (520mm)	11.54	0.01	1.10	n.s.	3.14	n.s.	0.24	n.s.	0.71	n.s.
Laminaria saccharina (0-180mm) (180-520mm) (520mm)	3.74	n.s.	3.25	n.s.	1.64	n.s.	- *	- *	1.13	n.s.
Fucus vesiculasus (0-180mm) (180-520mm) (520mm)	40.38	0.001	2.73	n.s.	2.79	n.s.	0.67	n.s.	0.03	n.s.
Patella vulgata (adult) (young) (soft parts)	0.14	n.s.	0.01	n.s.	0.84	n.s.	0.04	n.s.	3.17	n.s.
Patella vulgata (adult) (young) (shell)	1.50	n.s.	0.01	n.s.	0.08	n.s.	0.84	n.s.	- *	n.s.

n.s. not significant
* no data available

For 180mm read 200 mm
For 520mm read 500 mm

Fig. 4: Concentrations of heavy metals in two species of Laminaria



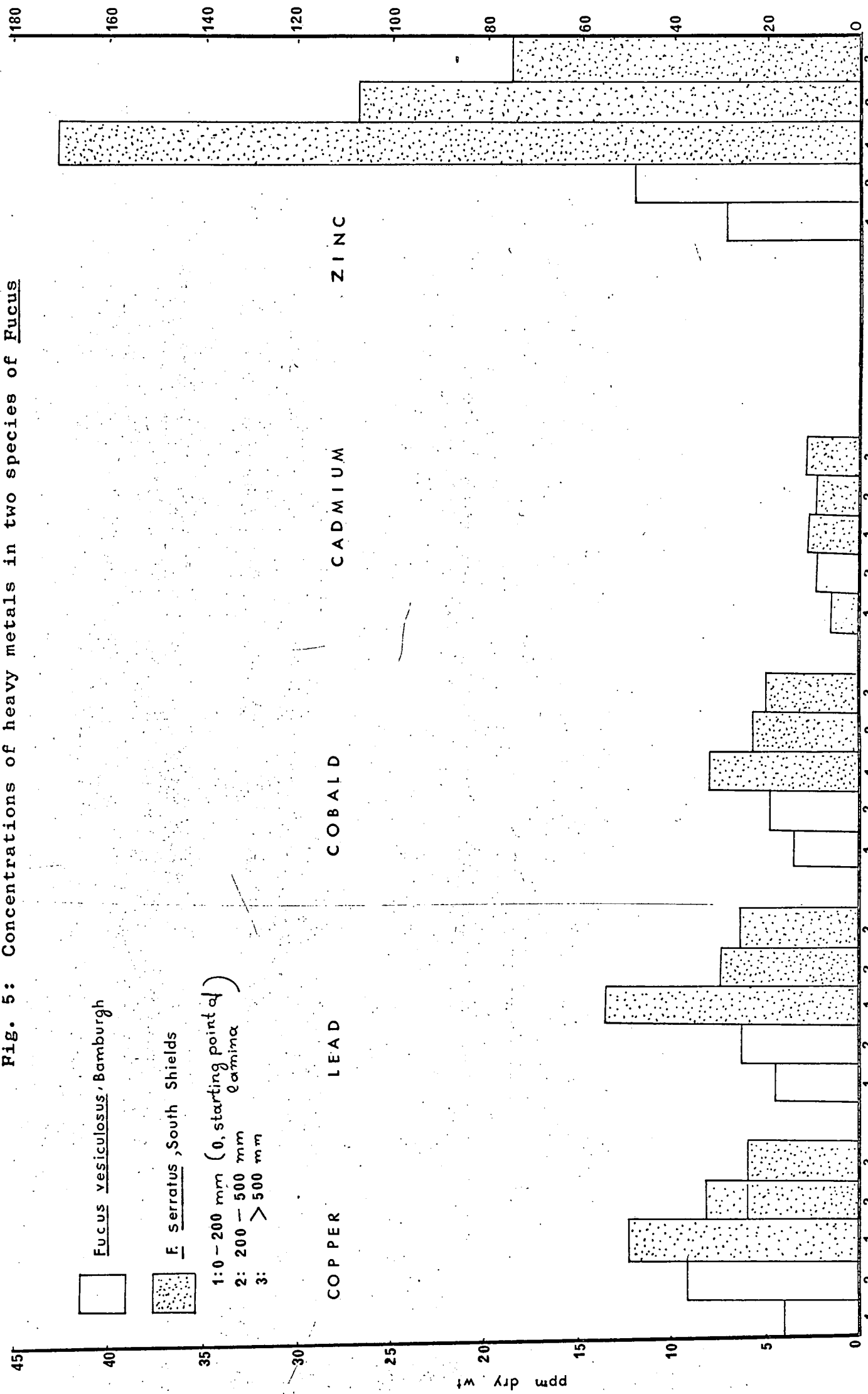


Fig. 5: Concentrations of heavy metals in two species of Fucus

4. DISCUSSION

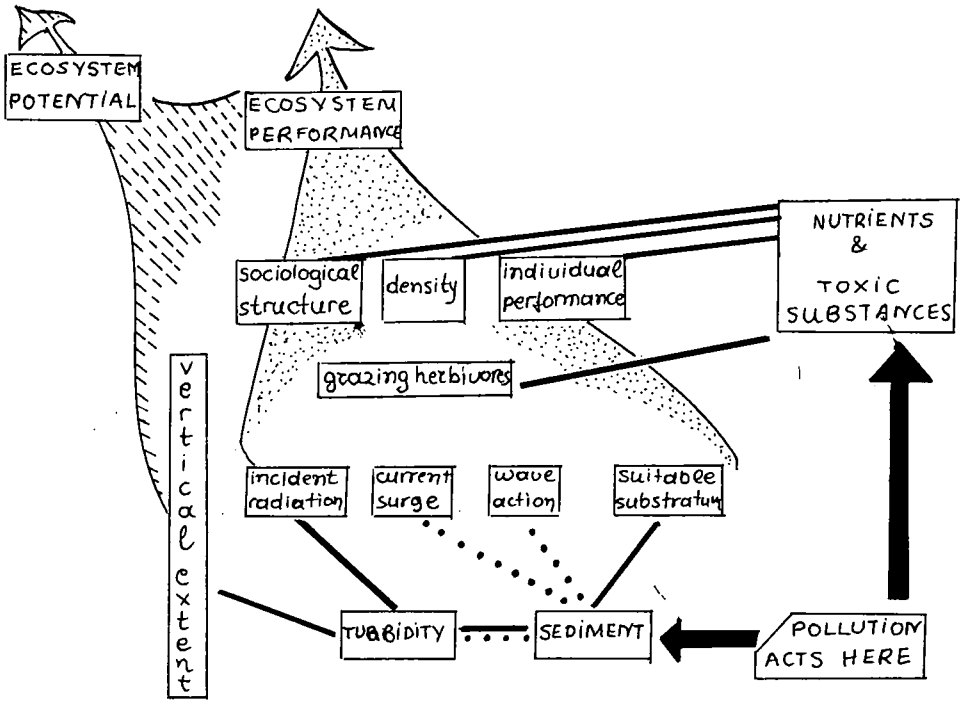


Fig. 6: Summary of factors affecting the rockpool ecosystems

Figure 6, redrawn from Bellamy et al., (1968) summarizes the complex of factors affecting the algal members of a rockpool ecosystem and indicates where pollution might act.

The present study was mainly centred upon the assessment of sociological structure by measuring species diversity and its related parameters, and the accumulation of toxicoids as a significant indicator of pollution, along the food chain of the rockpool community.

Species diversity

As shown in table IV, South Shields showed a reduction in the index of species diversity. However, both areas exhibited low indices of diversity which agrees with

Sander's conclusion that species diversity shows an inverse relationship to stress (Sanders, 1969). Besides pollution, these rockpool algal communities are subject to great environmental stresses and continuous fluctuations of abiotic parameters, such as diel and annual variations of temperature, oxygen concentration, pH and salinity (Ganning, 1971). The values obtained agree with those reported for macroinvertebrates in streams polluted with organic effluents, where values between 1 and 3, for species diversity, were recorded in areas of moderate pollution (Wilhm and Dorris, 1966). Contrastingly, the total number of species is opposite to the common belief, e.g. (Odum, 1971) that one of the effects of pollution is a reduction in species present. A possible reason might be the unexplicable increase in epiphytes at South Shields, e.g. Rhodymenia palmata, Ptilota plumosa, and Plumaria elegans existed as epiphytes at South Shields. It is interesting to note that although the number of the main dominant species remained approximately the same at both sites, the growth of certain algal species such as Enteromorpha and Ulva appeared to be favoured at the polluted site thus reducing the index of dominance. In an extreme situation i.e. a heavily polluted environment the above concept might not be true, because only few species would be favoured while the majority would be reduced to extinction. The slight difference in biomass at Bamburgh is probably due to a seasonal variation since there was one month's difference between the sampling of the two sites and a rapid plant growth was observed. Increase in total biomass as a result of pollution is not always expected (Golubic, 1970).

Toxicoids

When the two sites are compared according to heavy metal concentrations, South Shields exhibits a higher mean concentration in all five metals with notably high values in zinc and lead. Significantly higher concentrations in these two metals were found in the sediment. High values in the sediment might be very important to the circulation of heavy metals in the whole ecosystem. Parker et al., (1963), pointed out the significance of the top few cms of the sediment in the cycle of trace elements and the importance of the rate of movement from sediment to biosphere in the biochemistry of these elements. Sediments, because of the long-term build up of heavy metals, in addition to preventing growth, may have an affect on the settlement and establishment of certain algal species (Bryan, 1971). This affect may be important to the whole ecosystem since low diversity or poor growth of producers can lead to a reduction of diversity of primary and secondary consumers.

The data on the concentration of heavy metals by plants was mainly based on brown seaweeds which are considered to be good indicator systems (Preston, 1972). 'Good indicators' are organisms or parts of organisms which reflect the concentration of heavy metals in the water. Their use avoids misleading results, due to short-term fluctuations in the concentrations of trace elements in the abiotic components. Laminaria digitata is a good indicator of the concentration of zinc, lead and copper whereas Fucus vesiculosus reflects the concentrations of zinc, iron, manganese and silver (Bryan, 1971, Preston, 1972). Owing to a difference in the concentration of zinc in different

parts of perennial algae, as found by Bryan (1971), detailed study of the brown algae was carried out. Significant differences in the concentration of zinc were found in the various parts of both Fucus vesiculosus and Laminaria digitata. However, none of the other heavy metals showed such a difference nor was the concentration of zinc significantly different in the various parts of tissue of Laminaria saccharina and Fucus serratus. Therefore, it would seem possible to use any part of the algae for comparative studies for metals other than zinc. However, to overcome any such differences comparison was carried out between the same part of the algae in each case. Although in all cases there were higher concentrations in the plant and material collected from South Shields, the only significant difference obtained was when two different species of Fucus were compared (Table IX). These are probably interspecific rather than intersite differences. Therefore, one should be careful when making comparisons between species of the same genus.

Analysis of members of the food chain from higher trophic levels did show a number of significant differences. The highest concentration of zinc was found in Patella vulgata which is a browsing form feeding upon the microscopic film that covers the rocks (Mullin et al., 1956). However, the highest concentrations in all five metals were found in the body of Carcinus maenas. Table XIV shows the concentrations of the heavy metals along the food chain. There is an obvious increase going from annual plants to omnivore animals.

Table XIV

Accumulation of toxicoids along the food chain (ppm dry wt)

Bamburgh	Zn	Cu	Pb	Co	Cd
plant (annual)	16	4	4	1	1
plant (perennial)	40	7	6	5	2
animal(herbivore)	58	14	7	1[illegible]	5
animal(omnivore)	53	15	11	27	7
South Shields					
plant (annual)	25	19	5	2	5
plant (perennial)	43	9	15	4	4
animal(herbivore)	112	21	18	6	6
animal (omnivore)	69	37	31	33	9

The reduction of zinc concentration in Carcinus maenas (omnivore) might be due to the regulation of the metal by the animal (Bryan, 1971).

However, heavy metals are not the only pollutants entering marine systems. Nutrients in both inorganic and organic form are also important. Addition of inorganic nutrients such as phosphates and nitrates can stimulate algal growth and to a certain extent enable algae to recover from the affect of toxicoids.

The concentration of nutrients at sites near the investigated areas are given in Table XV (Jones, 1970). Seahouses is a site near Bamburgh whereas Souter is found north of South Shields.

Table XV

Concentration of inorganic nutrients in mg/litre

	PO_4	NO_3	NO_2	NH_4	SiO_2
Seahouses:	0.99	14.3	0.29	8.0	7.25
Souter:	3.78	19.0	3.25	13.5	19.50

Table XV shows an obvious increase in nutrients at Souter.

A simultaneous study of nutrients and toxicoids at both sites, including their relation to other changing abiotic parameters such as pH, salinity, O_2 concentration turbidity etc., throughout the year, could possibly lead to a better understanding of the functioning of the ecosystems at both sites and a better appreciation of the toxicity levels of the heavy metals to the various organisms.

In summary, there is evidence that the rock pool systems of the polluted site differ from that of the unpolluted site in a number of ways. The reduction in the diversity of the algal components of the rockpool ecosystems and the higher levels of heavy metals at South Shields as compared with those at Bamburgh are what would be expected between two sites along a pollution gradient. The increased number of species in the polluted pools could well reflect the presence of other pollutants such as phosphate and nitrate which would have a beneficial effect on the ecesis and growth of the algae. Synergism between heavy metals and nutrients would appear to be a fruitful sphere for further research.

5. SUMMARY

Two mid-littoral rockpool ecosystems were investigated in relation to marine pollution. Two sites were selected along the pollution gradient in the north east of England, South Shields (polluted) and Bamburgh (unpolluted). Comparative studies of the total ecosystem were carried out using species diversity as an indicator of pollution stress. Suspended matter, sediment and the following members of the food chain were analysed for zinc, copper, lead, cobalt and cadmium. Primary producers: Ulva Lactuca, Rhodymenia palmata (annuals), Laminaria digitata, L. saccharina, Fucus serratus, F. vesiculosus (perennials). Herbivores: Patella vulgata, Littorina littorea and an omnivore, Carcinus maenas.

The polluted site showed both lower diversity and significantly higher concentration of heavy metals than the unpolluted site. The results are discussed and problems related to the interaction of various types of pollutants are indicated.

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